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Time for action: science education for an alternative future

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Following a brief historical survey of the popular 'slogans' that have influenced science education during the past quarter century and a review of current international debate on scientific literacy and science pedagogy, the author takes the view that while much of value has been achieved, there is still considerable cause for concern and that it is time for action in two senses. First, it is time to take action on the school science curriculum because it no longer meets the needs, interests and aspirations of young citizens. Second, it is time for a science curriculum oriented toward sociopolitical action. The author argues that if current social and environmental problems are to be solved, we need a generation of scientifically and politically literate citizens who are not content with the role of 'armchair critic'.

A particular concern in North America is the link between science education, economic globalization, increasing production and unlimited expansion – a link that threatens the freedom of individuals, the spiritual well-being of particular societies and the very future of the planet. The author's response is to advocate a politicized, issues-based curriculum focused on seven areas of concern (human health; food and agriculture; land, water and mineral resources; energy resources and consumption; industry; information transfer and transportation; ethics and social responsibility) and addressed at four levels of sophistication, culminating in preparation for sociopolitical action. The curriculum proposal outlined in the article is intended to produce activists: people who will fight for what is right, good and just; people who will work to re-fashion society along more socially-just lines; people who will work vigorously in the best interests of the biosphere. At the heart of this curriculum is a commitment to pursue a fundamental realignment of the values underpinning Western industrialized society. Achieving that goal is a formidable task – one that will not be achieved by conventional approaches to curriculum development and teacher education. The author's solution is action research linked to community involvement.

Then and now

The shifting emphases of science education debate over the past 30–40 years are clearly reflected in the numerous slogans and rallying calls that have gained prominence, including 'Being a Scientist for a Day' (from the early Nuffield science projects in the United Kingdom), 'Learning by Doing', 'Process, not Product', 'Science for All', 'Less is More', 'Children Making Sense of the World' and 'Science as a Way of Knowing'. From the early 1990s onwards, much debate has centred on another slogan: the notion of 'Scientific Literacy' and how to achieve it – a debate that shows little sign of slowing down or reaching resolution.

Although the attainment of scientific literacy has been almost universally welcomed as a desirable goal, there is still little clarity about its meaning (Jenkins, 1990; Eisenhart, Finkel & Marion, 1996; Galbraith, Carss, Grice, Endean & Warry, 1997; DeBoer 2000; Kolsto 2001; Laugksch 2000; Tippens, Nichols & Bryan,

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2000) and little agreement about precisely what it means in terms of curriculum provision. While some see scientific literacy as the capacity to read newspaper and magazine articles about scientific and technological matters with a reasonable level of understanding, others see it as being in possession of the knowledge, skills and attitudes essential to a career as a professional scientist, engineer or technician. While some argue for a broadening of the knowledge base of the science curriculum to include greater consideration of the interactions among science, technology and society (the STS emphasis), others urge curriculum decision makers to concentrate on the knowledge and skills deemed (by some) to be essential to continued economic growth and effective competition within the global marketplace. If it is correct that most people obtain their knowledge of contemporary science and technology from television and newspapers (National Science Board, 1998; Select Committee, 2000), then the capacity for active critical engagement with text is not only a crucial element of scientific literacy, it is perhaps the *fundamental* element. In that sense, education for scientific literacy has striking parallels with education in the language arts (Hewson, 2002; Norris & Phillips, 2003). But what else should be regarded as crucial? Understanding the nature of science? Knowledge of the major theoretical frameworks of biology, chemistry and physics, and their historical development? Awareness of the applications of science? Ability to use science in everyday problem solving?

In one early attempt at clarification, Pella, O'Hearn and Gale (1966) suggested that scientific literacy comprises an understanding of the basic concepts of science, the nature of science, the ethics that control the scientist in his [sic] work, the interrelationships of science and society, the interrelationships of science and the humanities, and the differences between science and technology. A quarter century later, *Science for All Americans* (American Association for the Advancement of Science (AAAS), 1989, p. 4) defined a scientifically literate person as

> 'one who is aware that science, mathematics, and technology are interdependent human enterprises with strengths and limitations; understands key concepts and principles of science; is familiar with the natural world and recognizes both its diversity and unity; and uses scientific knowledge and scientific ways of thinking for individual and social purposes.'

More recently, the Organization for Economic Cooperation and Development's (OECD) Programme for International Student Achievement (PISA) proposed that a scientifically literate person is

> 'able to combine science knowledge with the ability to draw evidence-based conclusions in order to understand and help make decisions about the natural world and the changes made to it through human activity' (OECD, 1998, p. 5).

There are strong echoes here of Arons' (1983) emphasis on the ability to

> 'discriminate, on the one hand, between acceptance of asserted and unverified end results, models, or conclusions, and on the other, understand their basis and origin; that is, to recognize when questions such as "How do we know?" "Why do we believe it?" "What is the evidence for it?" have been addressed, answered, and understood, and when something is being taken on faith' (p.93).

Similar capabilities have sometimes been included in the notion of *intellectual independence* (Munby, 1980; Aikenhead, 1990; Norris, 1997). Without such capabilities, citizens are 'easy prey to dogmatists, flimflam artists, and purveyors of simple solutions to complex problems' (AAAS, 1989, p. 13) – including, one might

add, some otherwise respectable scientists, politicians and commentators, who intimidate through their facility in a mode of discourse unfamiliar to many citizens.

Running alongside this debate about the goals of science education and the curriculum content required to achieve them has been a parallel debate about the design and implementation of better teaching and learning methods. While there have been some dissenters, it is probably fair to say that the dominant psychological influence on the science curriculum during the 25 years that *IJSE* has been published has been the constructivist view of learning and the pedagogy that is claimed to derive from it. Indeed, in many parts of the world, the promotion and acceptance of constructivism is such that it now has the characteristics of a 'new orthodoxy' of science education (Fensham, 1992), despite some strenuous criticisms that it neglects the rationality of science (Matthews, 1993) and over-emphasizes the rationality of learning (West & Pines, 1983). This latter point is of crucial significance because it leads directly to arguments for a greatly enhanced role for the affective and social dimensions of learning. Much attention in recent years has also been directed towards the development of more effective laboratory work and more extensive use of fieldwork (Wellington, 1998), and efforts to integrate formal classroom-based teaching with informal learning (museums, science centres, etc) and various forms of community-based learning (Helms, 1998; Pedretti, 2002).

During this same period, our views about science itself have undergone substantial revision. Recent scholarship in the history, philosophy and sociology of science has effected a major shift from the view that scientific knowledge is universal, coherent, objective and unproblematic towards recognition that it is sometimes uncertain, contentious and unable to provide clear, unambiguous answers to many important questions. There is increasing recognition among science educators that science is a product of its time and place, inextricably linked with its sociocultural and institutional location, and profoundly influenced by its methods of generation and validation.

In reflecting on the impact of these slogans, trends and movements in science education, there is much cause for satisfaction. The Science for All movement has led to a broadening of the student population exposed to science in the later years of schooling. There is also more science in the curriculum of primary (elementary) school than ever before. The STS movement has ensured some broadening of the scope of science education and, to some extent, has broadened the conception of science itself. Students now study something about the ways in which scientists work and the methods by which knowledge is created and validated. There is increasing recognition of the need to look at the wider social, political, economic and ethical issues that surround the practice of science. While issues of inequity related to gender and ethnicity have not always been solved, at least they have been raised. Teaching and learning methods have been extended in interesting new directions: there is now much less emphasis on the acquisition of factual knowledge via direct instruction and correspondingly greater emphasis on active learning; there are more opportunities for students to engage in their own scientific investigations; teachers are beginning to use assessment and evaluation practices inspired by notions of authentic assessment, performance-based assessment and educative assessment.

However, while much has been achieved, there is still considerable cause for concern. Many students still do not learn much of what we intend: their scientific

knowledge and their capacity to use that knowledge effectively and purposefully fall well short of our intentions; their understanding of the nature and methods of science are often incoherent, distorted and confused. The motivation for science that is so apparent in the early years of schooling often dissipates as students progress through secondary school, leading many to drop out of science at the earliest opportunity. In many educational jurisdictions, the imposition of strict new assessment regimes have led to the absurd situation in which teachers seem to spend almost as much time measuring student competence in science as they do in developing it.

What of the future?

While we can be certain that the curriculum will change over the next 25 years, perhaps only a fool would attempt to predict the directions of that change. Nonetheless, we can identify some of the many factors that will drive that change, including the changing nature of society and the expectations that society has for education (and for science and technology education in particular), increasing ethnic diversity of the school population, rapid advances in science and technology, changes in our understanding of how students acquire and develop complex scientific understanding, increased awareness of the significance of the affective and social dimensions of learning, the impact of new technologies on classroom practice, shifts in the relative influence afforded to different stakeholders in education (students, parents, teachers, scientists, business interests), and so on.

While it may be unwise to predict, we may still choose to speculate on possibilities, or, the more usual province of university-based science educators, advocate particular changes. The proposals I outline in this article are located in some discernible trends: principally, the broadening conception of STS to include environmental education (STS becomes STSE), extending the definition of scientific literacy to encompass a measure of political literacy, prioritizing the affective, and making much greater use of informal and community-based learning opportunities. More importantly, perhaps, the proposals are driven by a commitment to address the social, cultural and environmental 'fallout' from the current North American concern to link business interests, economic growth and scientific literacy.

First, an observation: in previous generations, we have been able to predict the kind of knowledge, skills and attitudes that students currently in school would need for a lifetime of employment. Now, for the first time in history, we are educating students for life in a world about which we know very little, except that it will be characterized by substantial and rapid change, and is likely to be more complex and uncertain than today's world. For some, this is an exciting prospect; for others, it is profoundly disconcerting, even frightening. The question I pose is: 'What kind of science education is appropriate as preparation for this relatively unknown world?' It is important to emphasize that the concerns and proposals discussed in this article relate to science education in Western, industrialized societies. While many similar general concerns arise for science education in the developing world, the specific local matters that usually take precedence are outside the scope of the article.

We live in a very different world from the world of 1978. In the quarter century since issue 1 of *IJSE* appeared, science has lost much of the innocence and purity afforded to it by the creators of the major curriculum advances of the 1960s – Physical Science Study Committee (PSSC), Chemical Education Materials Study

(Chem Study), and Biological Sciences Curriculum Study (BSCS) in the United States, and the various Nuffield and Schools Council courses in the UK. A succession of human and environmental tragedies have sometimes cast science in the role of villain; disturbing social changes and deep ethical concerns arising from scientific and technological innovations have caused science to be viewed by many as a potential threat to familiar and comfortable ways of life; the increasing commercialization, industrialization and militarization of science have shown once and for all that science is not value-free and disinterested. The merger of science and technology into technoscience, the appropriation of the knowledge-making capacity of science to promote the interests of the rich and powerful, and the usurping of the scientific and technological endeavour for the goal of ever-increasing levels of material consumption, have profoundly changed the sociopolitical and moral-ethical contexts of scientific and technological practice. To what extent has the school science curriculum responded to these changes? To what extent have curriculum makers addressed the level of cynicism and disaffection for science and technology created by these changes, with its adverse impact on enrolment in science and engineering?

The principal response, of course, has been the development of STS courses (Solomon & Aikenhead, 1994; Yager, 1996). However, while there have been some notable successes, STS materials have often

> 'lacked an adequate theoretical foundation and have served a limited, if valuable, function of supporting and enriching otherwise conventional school science courses' (Jenkins, 2002, p. 19).

School science courses, especially in the later years, continue to be dominated by the basic disciplines of physics, chemistry and biology. There is very little in the way of integration and, in many countries, scant attention given to the earth sciences and environmental science. Consequently, in 1997 and 1998, the Nuffield Foundation funded a series of 'closed seminars' and 'open meetings' of science educators in an attempt to formulate a more comprehensive vision of science education and what it can and should achieve. The Report, *Beyond 2000: Science Education for the Future* (Millar & Osborne, 1998), concludes that the National Curriculum for England and Wales has failed to meet the needs of contemporary society, much less anticipated the needs of future society. The authors acknowledge that

> 'the changing curricular position of science has not been accompanied by corresponding change in the *content* of the science curriculum . . . This has remained fundamentally unaltered and is, essentially, a diluted form of the 1960s GCE curriculum' (p.4),

that is, an abstract, academic curriculum. Among the ten recommendations for change is the proposal that scientific knowledge be presented as a number of 'explanatory stories' – '*inter-related sets of ideas* which, taken together, provide a framework for understanding an area of experience' (p.13, emphasis in original). There should be more emphasis on technology and the applications of science; greater attention should be given to the social processes used to generate, test and scrutinize knowledge claims; teachers should employ a wider range of teaching and learning approaches, including the use of case studies of historical and current issues; new and broader approaches to assessment should be devised and implemented in order to focus attention on the more important aspects of learning. Throughout the document, the case for the importance of scientific literacy (largely defined in terms of conceptual and methodological knowledge, with some

sociocultural dimensions) is strongly and repeatedly made, thus reinforcing the view of some critics that this is yet another attempt to rescue a conventional science education in crisis rather than a commitment to radically reshape the nature and purpose of the curriculum.

> Our view is that the primary and explicit aim of the 5–16 science curriculum should be to provide a course which can enhance 'scientific literacy', as this is necessary for all young people growing up in our society, whatever their career aspirations or aptitudes . . . school science education should aim to produce a populace who are comfortable, competent and confident with scientific and technical matters and artefacts. The science curriculum should provide sufficient scientific knowledge and understanding to enable students to read simple newspaper articles about science, and to follow TV programmes on new advances in science with interest. Such an education should enable them to express an opinion on important social and ethical issues with which they will increasingly be confronted. It will also form a viable basis, should the need arise, for retraining in work related to science or technology in their later careers. (Millar & Osborne, 1998, p.9)

In his highly provocative work, *The Myth of Scientific Literacy*, Shamos (1995) argued that the pursuit of universal scientific literacy is a futile goal because its elements (as briefly outlined in documents such as *Beyond 2000* and *Science For All Americans*) are so wide ranging that they cannot be achieved – and certainly not for everyone. Moreover, he declared, scientific literacy in any of the senses relating to science content isn't necessary anyway. Most people can get along perfectly well without scientific knowledge or can easily access it when the need arises. Indeed, many people who are otherwise successful in their lives proudly proclaim their ignorance of, and lack of interest in, science. After all, many people use VCRs, drive cars and deploy computers with little or no understanding of the science that underpins their manufacture and operation. Perhaps the consequence of life as an 'ignorant consumer' is precisely why we need to ensure universal scientific literacy, though I have much sympathy for Layton, Jenkins, MacGill and Davey (1993) when they describe a very different kind of scientific literacy, what they call 'practical knowledge in action'. The science needed for solving the problems of everyday life, they argue, is very different in form from that presented via the school curriculum. This strand of argument has prompted Peter Fensham (2002) to state that it is 'time to change drivers for scientific literacy' and to abandon the traditional ways of identifying science content knowledge for the school curriculum. More in line with Fensham's recommendation would be a curriculum designed in accordance with the findings described by Law (2002) arising from a study in which she and her co-researchers asked leading scientists, health care professionals, local government representatives, managers and personnel officers in manufacturing industry, and the like, about the kind of science and the kind of personal attributes and skills that are of most value in persons employed in their field of expertise.

In speculating about or advocating for the future school science curriculum, there are two questions to consider. First, 'Is scientific literacy necessary?' Second, 'Is it sufficient?' Perhaps life in the 21st century will demand higher levels of scientific literacy than were previously required of citizens. Perhaps not. What is clear is that ordinary citizens will increasingly be asked to make judgements about matters underpinned by science knowledge or technological capability, but overlaid with much wider considerations. Those without a basic understanding of the ways in which science and technology are impacted by, and impact upon, the physical and the sociopolitical environment will be effectively disempowered and susceptible to being seriously misled in exercising their rights within a democratic, technologically-

dependent society. It is this concern for the vulnerability of the scientifically illiterate to the blandishments of politicians and corporate advertizing that leads directly to my next consideration: the social, cultural and environmental 'fallout' from the current drive to link business interests, economic growth and scientific literacy.

Corporatism versus democracy?

In recent years, the economic argument for scientific literacy has become the predominant one in North America. It is both powerful and persuasive, as illustrated by the Government of Canada's (1991) attempt to establish a link between school science education and a culture of lifelong learning as the key to the country's prosperity.

> Our future prosperity will depend on our ability to respond creatively to the opportunities and challenges posed by rapid change in fields such as information technologies, new materials, biotechnologies and telecommunications . . . To meet the challenges of a technologically driven economy, we must not only upgrade the skills of our work force, we must also foster a lifelong learning culture to encourage the continuous learning needed in an environment of constant change. (Government of Canada, 1991, pp. 12, 14)

The power of a particular discourse is located in the ways in which it determines how we think about society and our relations with others, and in its impact on how we act in the world. Lankshear, Gee and Hull (1996) use the term *fast capitalist texts* to describe the business and management books, company policy documents and media pronouncements which have now become mainstream popular cultural interpretations of the 'proper' nature of work and commerce in newspapers, magazines, radio and television. Language has been transformed by industry and corporate business leaders into a sociotechnical device capable of creating and sustaining new social relationships between managers and workers, and imposing particular capitalist values on workers. In other words, transnational businesses have created and sustained a discourse that serves their immediate and future needs, and have extended this discourse to schools and the education system. In order to design, develop, optimize, produce and market goods and services for the global marketplace, industry claims to need a flexible, 'just-in-time' and compliant workforce, which it is the education system's job to provide. Seemingly, at least in Ontario, the corporate world has been successful in exerting its will on the school curriculum, as witness this statement from the Ministry of Education and Training (2000, p.3):

> The new Ontario curriculum establishes high, internationally competitive standards of education for secondary school students across the province. The curriculum has been designed with the goal of ensuring that graduates from Ontario secondary schools are well prepared to lead satisfying and productive lives as both citizens and individuals, and to compete successfully in a global economy and a rapidly changing world.

The pressures exerted by business and industry on schools to provide more 'job ready' people can be seen as part of an overt sociotechnical engineering practice in which new capitalism is creating 'new kinds of people by changing not just their overt viewpoints but their actual practices' (Lankshear et al. 1996, p. 22). It is re-engineering people in its own image! Indeed, there are many who view these developments as symptomatic of a dangerous trend, both for individuals and for society as a whole, part of what Bencze (2001) calls

> 'an *apprenticeship for consumership* – that is, creation of a large mass of . . . citizens who simultaneously serve as loyal workers and voracious, unquestioning consumers' (p. 350).

In similar vein, Apple (1993) states that in this new economy-driven educational climate, students are no longer seen as people who will participate in the struggle to build and rebuild the social, educational, political and economic future, but as consumers; freedom is

> 'no longer defined as participating in building the common good, but as living in an unfettered commercial market, with the education system . . . integrated into the mechanisms of such a market' (p.116).

When school presents students, almost daily, with a language that promotes economic globalization, increasing production and unlimited expansion, identifies technology with unfettered 'progress', work with money and excellence with competition and 'winning at any cost', it is implicated in the manufacture and maintenance of what Bowers calls the *myths of modernity*:

> 'that the plenitude of consumer goods and technological innovation is limited only be people's ability to spend, that the *individual* is the basic social unit . . . and that science and technology are continually expanding humankind's ability to predict and control their own destiny' (Bowers, 1996, p. 5, emphasis added).

At risk here are the freedoms of individuals, the spiritual well-being of particular societies, and the very future of the planet. In Edmund O'Sullivan's (1999, p.27) words:

> Our present educational institutions which are in line with and feeding into industrialism, nationalism, competitive transnationalism, individualism, and patriarchy must be fundamentally put into question. All of these elements together coalesce into a world view that exacerbates the crisis we are now facing.

Little of the world's poverty, injustice, terrorism and war will be eliminated, and few of current environmental crises (ozone depletion; global warming; land, air and water pollution; increasing deforestation and desertification; loss of biodiversity) will be solved, without a major shift in the practices of Western industrialized society and the values that currently sustain them. Interestingly, one of the keys to ameliorating the current situation may lie in increased levels of scientific literacy among the world's citizens – but a different kind of scientific literacy. As the authors of *Benchmarks for Scientific Literacy* (AAAS, 1993) suggest,

> 'People who are literate in science . . . are able to *use* the habits of mind and knowledge of science, mathematics, and technology they have acquired to think about and make sense of many of the ideas, claims, and events that they encounter in everyday life' (p. 322, emphasis added).

The authors of *Science For All Americans* (AAAS, 1989, p.12) direct attention towards scientific literacy for a more socially compassionate and environmentally responsible democracy when they state that science can provide knowledge 'to develop effective solutions to its global and local problems' and can foster 'the kind of intelligent respect for nature that should inform decisions on the uses of technology' and without which, they say, 'we are in danger of recklessly destroying our life-support system'. Regrettably, they don't go on to suggest that scientific literacy also includes the capacity and willingness to act in environmentally responsible and socially just ways. This component is also absent from the definition

proposed by the Council of Ministers of Education (1997, p.4) to guide curriculum construction throughout Canada:

> 'scientific literacy is an evolving combination of the science-related attitudes, skills, and knowledge students need to develop inquiry, problem-solving, and decision-making abilities, to become lifelong learners, and to maintain a sense of wonder about the world around them'.

Because, they say, 'it conveys more clearly a flavour of science education for action as well as for personal enlightenment and satisfaction', the Scottish Consultative Council on the Curriculum (SCCC, 1996, p.15) adopted the term *scientific capability* instead of scientific literacy. Scientific capability is described in terms of five distinct, but clearly interrelated, aspects: scientific *curiosity* – an enquiring habit of mind; scientific *competence* – ability to investigate scientifically; scientific *understanding* – understanding of scientific ideas and the way science works; scientific *creativity* – ability to think and act creatively; and scientific *sensitivity* – critical awareness of the role of science in society, combined with a caring and responsible disposition. Hence, becoming 'scientifically capable' involves considerably more than the acquisition of scientific skills, knowledge and understanding. It also involves the development of personal qualities and attitudes, the formulation of one's own views on a wide range of issues that have a scientific and/or technological dimension, and the establishment of an underlying value position. In the words of the SCCC (1996, p.15),

> 'a person who is scientifically capable is not only knowledgeable and skilled but is also able to draw together and apply her/his resources of knowledge and skill, creatively and with sensitivity, in response to an issue, problem or phenomenon'.

It is interesting and extremely disappointing that a document purporting to be action-oriented does not include preparation for sociopolitical action by students in its definition of scientific capability. If we are to tackle the crisis (crises) that O'Sullivan identifies, we need a much more overtly politicized form of science education, a central goal of which is to equip students with the capacity and commitment to take appropriate, responsible and effective action on matters of social, economic, environmental and moral-ethical concern.

It is timely, then, that the pendulum of education policy in England and Wales may now be moving away from a focus on producing a suitably educated workforce towards a wider socialization and development role. The so-called Crick report, responding to what the authors perceived as 'worrying levels of apathy, ignorance and cynicism about public life' (Qualifications & Curriculum Authority (QCA), 1998, p.8), has recommended the immediate implementation of *education for citizenship* comprising three strands: social and moral responsibility, community involvement and political literacy.

> We aim at no less than a change in the political culture of this country both nationally and locally: for people to think of themselves as active citizens, willing, able and equipped to have an influence in public life and with the critical capacities to weigh evidence before speaking and acting; to build on and to extend radically to young people the best in existing traditions of community involvement and public service, and to make them individually confident in finding new forms of involvement and action among themselves (QCA, 1998, p.8)

This radical agenda would require a very different conception of scientific literacy – one in which emphasis is not just on scientific knowledge and skills, but on the clarification of problems and negotiation of possible solutions through open,

critical dialogue and active participation in democratic mechanisms for effecting change. As McConnell (1982) remarked, some twenty years ago,

> 'Public decision making by citizens in a democracy requires an attitude of attentiveness; skills of gaining and using relevant knowledge; values of which one is aware and to which one is committed; and the ability to turn attitudes, skills and values into action' (p.13).

The curriculum proposals outlined in this article are designed to achieve these goals.

Politicizing the science and technology curriculum

One of the absurdities of some current curriculum initiatives is that they utilize elements of the history, philosophy and sociology of science to show how scientific inquiry is influenced by the sociocultural context in which it is located but do not use this understanding to politicize students. Many teachers avoid confronting the political interests and social values underlying the scientific and technological practices they teach about, and seek to avoid making judgements about them or influencing students in particular directions. This makes little or no sense. First, it asks teachers to attempt the impossible. Values are embedded in every aspect of the curriculum: content, teaching/learning methods and assessment/evaluation strategies are selected using criteria that reflect and embody particular value positions, whether teachers recognize it or not. Moreover, values can be promoted as much by what is omitted from discussion as by what is included. Second, it mistakes the very purpose of the science component of education for citizenship: ensuring a level *critical* scientific and technological literacy for everyone as a means to bring about social reconstruction. The purpose of such an education is to enable young citizens to look critically at the society we have, and the values that sustain it, and to ask what can and should be changed in order to achieve a more socially just democracy and to ensure more environmentally sustainable lifestyles. This view of science education is overtly and unashamedly political. It takes the Advisory Group on Education for Citizenship and the Teaching of Democracy in Schools (QCA, 1998) at its word – not just education *about* citizenship, but education *for* citizenship.

> . . . citizenship education is education *for* citizenship, *behaving and acting as a citizen*, therefore it is not just knowledge of citizenship and civic society; it also implies developing values, skills and understanding (p.13, emphasis added).

Politicization of science education can be achieved by giving students the opportunity to confront real world issues that have a scientific, technological or environmental dimension. By grounding content in socially and personally relevant contexts, an issues-based approach can provide the motivation that is absent from current abstract, de-contextualized approaches and can form a base for students to construct understanding that is personally relevant, meaningful and important. It can provide increased opportunities for active learning, collaborative learning and direct experience of the situatedness of scientific and technological practice. In the Western contemporary world, technology is all pervasive; its social and environmental impact is clear; its disconcerting social implications and disturbing moral-ethical dilemmas are made apparent almost every day in popular newspapers and TV news bulletins. In many ways, it is much easier to recognize how technology is determined by the sociocultural context in which it is located than to see how science is driven by such factors. It is much easier to see the environmental impact of technology

than to see the ways in which science impacts on society and environment. For these kinds of reasons, it makes good sense to use problems and issues in technology and engineering as the major vehicles for contextualizing the science curriculum. This is categorically not an argument against teaching science; rather, it is an argument for teaching the science that informs an understanding of everyday technological problems and may assist students in reaching tentative solutions.

In constructing a new science and technology curriculum for the 21st century, my inclination is to provide a mix of local, regional/national and global issues focusing on seven areas of concern: human health; food and agriculture; land, water and mineral resources; energy resources and consumption; industry (including manufacturing industry, the leisure and service industries, biotechnology, and so on); information transfer and transportation; freedom and control in science and technology (ethics and social responsibility). Although my focus is science education in the Western world, it is apparent that very similar concerns impact curriculum debate in the developing world (Lee, 1992; Vlaardingerbroek, 1998; Dillon, 2002). Indeed, science teachers in Botswana regard 'reducing the spread of HIV/AIDS' as the principal goal of science education, while 'promoting environmental awareness and an active interest in preserving and maintaining the natural environment', 'promoting healthy diet and avoidance of drugs' and 'promoting human population control' are ranked third, fourth and fifth (Vlaardingerbroek, 1998).

As argued elsewhere (Hodson, 1994), the kind of issues-based approach I am advocating can be regarded as comprising four levels of sophistication.

- *Level 1*: Appreciating the societal impact of scientific and technological change, and recognizing that science and technology are, to some extent, culturally determined.
- *Level 2*: Recognizing that decisions about scientific and technological development are taken in pursuit of particular interests, and that benefits accruing to some may be at the expense of others. Recognizing that scientific and technological development are inextricably linked with the distribution of wealth and power.
- *Level 3*: Developing one's own views and establishing one's own underlying value positions.
- *Level 4*: Preparing for and taking action.

At the simplest level, case studies of the societal impact of inventions such as the steam engine, the internal combustion engine, the printing press or the computer can be used to bring about an awareness that science and technology are powerful forces that shape the lives of people and other species, and impact significantly on the environment as a whole. They can also be used to show that scientific and technological developments are both culturally dependent and culturally transforming. In other words, science is a product of its time and place and can sometimes change quite radically the ways in which people think and act. For example, the science of Galileo, Newton, Darwin and Einstein changed our perception of humanity's place in the universe and precipitated enormous changes in the way people address issues in politics, economics and history. This 'Level One awareness' also includes recognition that the benefits of scientific and technological innovations are often accompanied by problems: hazards to human health, challenging and sometimes disconcerting social changes, environmental degradation and major moral-ethical dilemmas.

Much of STS and environmental education, while recognizing these adverse features of development, is currently pitched at the level where decision-making in science and technology is seen simply as a matter of reaching consensus or effecting a compromise. In contrast, the intention at Level Two is to enable students to recognize that scientific and technological decisions are taken in pursuit of particular interests, justified by particular values and sometimes implemented by those with sufficient economic or political power to override the needs and interests of others. As a consequence, the advantages and disadvantages of scientific and technological developments often impact differentially on society. Case studies can be used to achieve a level of critical scientific literacy that recognizes how science and technology serve the rich and the powerful in ways that are often prejudicial to the interests and well-being of the poor and powerless, sometimes giving rise to further inequalities and injustices. Such studies help students to see that material benefits in the West (North) are often achieved at the expense of those living in the Developing World. It is here that the radical political character of the curriculum begins to emerge. Those curricula that take the trouble to address the symptoms of Third World poverty (malnutrition and famine, inadequate sanitation, and diseases such as rickets, tuberculosis and cholera) usually neglect to include a sociopolitical and historical analysis of its cause. Often, they treat the issue of poverty as a consequence of climatic harshness, overpopulation and ignorance. By contrast, the approach advocated here would recognize the role played by Western governments and business interests in controlling the production and distribution of resources. Students would quickly recognize that critical consideration of scientific and technological development is inextricably linked with questions about the distribution of wealth and power. Moreover, they would begin to see the ways in which problems of environmental degradation are rooted in societal practices and in the values and interests that sustain and legitimate them.

Level Three is concerned primarily with supporting students in their attempts to formulate their own opinions on important issues and to establish their own value positions, rather than with promoting the 'official' or textbook view. It focuses much more overtly on values clarification, developing strong feelings about issues, and actively thinking about what it means to act wisely, justly and 'rightly' in particular social, political and environmental contexts (Beck, 1990, 1993). This phase has much in common with the goals of Peace Education (Hicks, 1988) and Global Education (Selby, 1995). It begins with the fostering of self-esteem and personal well-being in each individual, and extends to respect for the rights of others, mutual trust, the pursuit of justice, cooperative decision-making and creative resolution of conflict between individuals, within and between communities, throughout the world. It is driven by a deep commitment to anti-discriminatory education – exposing the common roots of sexism, racism, homophobia, Eurocentrism and Westism (or Northism) in the tendency to dichotomize and generate a sense of *other*; working actively to confront the 'us and them' mentality that invariably sees 'us' as the norm, the desirable and the superior. It culminates in a commitment to the belief that alternative voices can and should be heard in order that decisions in science and technology reflect wisdom and justice, rather than powerful sectional interests (Maxwell, 1984, 1992).

The final (fourth) level of sophistication in this issues-based approach is helping students to prepare for and take responsible action. Socially and environmentally responsible behaviour will not necessarily follow from knowledge of key concepts

and possession of the 'right attitudes'. It is almost always much easier to proclaim that one cares about an issue than to do something about it! The keys to the translation of knowledge into action are *ownership* and *empowerment*. Those who act are those who have a deep personal understanding of the issues (and their human and environmental implications) and feel a personal investment in addressing and solving the problems. Those who act are those who feel personally empowered to effect change, who feel that they can make a difference, and know how to do so. Preparing students for action necessarily means ensuring that they gain a clear understanding of how decisions are made within local, regional and national government, and within industry, commerce and the military. Without knowledge of where and with whom power of decision-making is located, and awareness of the mechanisms by which decisions are reached, intervention is not possible. Furthermore, the likelihood of students becoming active citizens is increased substantially by encouraging them to take action *now* (in school), and by providing opportunities for them to do so. Suitable action might include conducting surveys of dump sites, public footpaths and environmentally sensitive areas, generating data for community groups such as birdwatchers and ramblers, making public statements and writing letters, organizing petitions and consumer boycotts of environmentally unsafe products, publishing newsletters, lobbying local government officials, working on environmental clean-up projects, creating nature trails, assuming responsibility for environmental enhancement of the school grounds, monitoring the school's consumption of energy and material resources in order to formulate more appropriate practices, and so on. It is not enough for students to learn that science and technology are influenced by social, political and economic forces; they need to learn how to participate, and they need to experience participation. It is not enough for students to be armchair critics! As Kyle (1996, p.1) puts it:

> Education must be transformed from the passive, technical, and apolitical orientation that is reflective of most students' school-based experiences to an active, critical, and politicized life-long endeavour that transcends the boundaries of classrooms and schools.

It is easy to see the potential for politicization in the seven areas of concern listed above: Human Health (for example, health goals in North America versus Third World, priorities in health spending, gender issues relating to 'body image'); Land, Water and Mineral Resources (for example, land usage issues, including Aboriginal land rights and efforts to formulate an Antarctic Treaty, water pollution, sustainable consumption); Food and Agriculture (politics of starvation, factory farming, genetically modified food); Energy Resources (renewable energy sources, politics of the petroleum industry, consumption and lifestyle issues); Industry (employment considerations versus environmental impact, sustainabliity issues, automation); IT and Transportation (data protection issues, cultural imperialism, emission controls); Ethics (genetic engineering; Third World organ donors, Hippocratic oath for scientists and engineers). It is also relatively easy to see how these areas of concern lend themselves to treatment at the four levels of sophistication. At level 1, students are made aware of the societal and environmental impact of science and technology and alerted to the existence of alternative technologies, with different impact. At level 2, they are sensitized to the sociopolitical nature of scientific and technological practice. At level 3, they become committed to the fight to establish more socially just and environmentally

sustainable practices. At level 4, they acquire the knowledge and skills to intervene effectively in decision-making processes and to ensure that alternative voices, and their underlying interests and values, are brought to bear on policy decisions. Some of the issues addressed through this curriculum will be global (ozone depletion, acid rain, global warming), some will be local (factory-based pollution, road construction, loss of recreational space), but the common element should be *sustainability*. How can economic and scientific/technological development be maintained in a way that values and protects the natural and social environment? As will be argued later, this challenge is as much social as it is scientific-technological.

In advocating a 4-level model, my intention is not to suggest that all action is delayed until the final years of schooling. Rather, that students proceed to whatever level is appropriate to the topic in hand, the learning opportunities it presents and the stage of intellectual and emotional development of the students, bearing in mind the simple class management principle of investing each topic with a degree of variety. In some areas of concern it is relatively easy for students to be organized for action; in other areas it is more difficult. It is also the case that, for some topics, level 3 is more demanding than Level 4. For example, it is easier to take action on recycling than to reach a considered and critical judgement of recycling versus reduced consumption versus alternative materials.

Elements of curriculum

Perhaps I can clarify what I have in mind by addressing the four major components of such a curriculum.

- *Learning Science and Technology*: acquiring and developing conceptual and theoretical knowledge in science and technology, and gaining familiarity with a range of technologies
- *Learning About Science and Technology*: developing an understanding of the nature and methods of science and technology, an awareness of the complex interactions among science, technology, society and environment, and a sensitivity to the personal, social and ethical implications of particular technologies.
- *Doing Science and Technology*: engaging in and developing expertise in scientific inquiry and problem solving; developing confidence and competence in tackling a wide range of 'real world' technological tasks.
- *Engaging in Sociopolitical Action*: acquiring the capacity and commitment to take appropriate, responsible and effective action on matters of social, economic, environmental and moral-ethical concern.

To an extent, items 3 and 4 can be combined by engaging students in science/technology problem-solving situations that have a community dimension, as described by Sutti (1991), Paton (1994), Albone, Collins and Hill (1995), van Marion (1995, 1998), Cunniff and McMillen (1996), Helms (1998), Lee and Roth (2002), Roth (2002), Roth and Lee (2002). Many students will already be aware of politically active organizations such as Greenpeace, the Sierra Club, World Wildlife Fund and Earthwatch. Education at level 4 includes both a study of what these organizations are trying to achieve and the methods they employ. Much can be learned that is applicable to local contexts.

While space precludes a detailed consideration of each of these elements, one or two important points can be made. As Fensham (1990) and Layton et al (1993) have observed, the conceptual understanding needed to address issues in technology and engineering is often somewhat different from the abstract, idealized knowledge of conventional science courses. Moreover, the precise relationship between the theoretical knowledge of science (knowing *that*) and the practical knowledge of technology (knowing *how*) is not always simple and straightforward. The history of science and technology reveals four possibilities: science precedes technological application (technology as applied science); technology precedes the science that eventually explains it; scientific development and technological development are entirely independent; scientific and technological development are mutually dependent and interactive. Layton (1988) makes the point that even when technology is 'just' applied science, there is still lots more to do. He gives the example of Perkin's development of mauve, and says that its translation into a commercial product required 'knowledge, skills and personal qualities very different from those needed for the test tube oxidation of aniline' (p.371). At the outset, mauve would not take evenly on large batches of cloth, there was no suitable mordant for cotton, raw materials were not readily available, handling concentrated nitric and sulphuric acids on a 'factory scale' presented all manner of engineering problems, there were problems of marketing associated with consumer reluctance, and so on. Notions such as optimization, feedback modelling, systems analysis, critical path planning and risk assessment have to be included whenever science is applied to these 'real world' situations.

Of course, real world problems are rarely the simple matters of cause and effect portrayed in traditional science curricula; rather, attempts at solution often reveal layers of increasing complexity and uncertainty that cannot be contained within a particular disciplinary framework. Problems in science and technology become inextricably linked with considerations in economics, politics, aesthetics and moral philosophy. In general, a scientific solution is valid/acceptable if it conforms to the rationality of science – i.e., if it has observational or experimental support, if it is internally consistent, if it is consistent with other accepted theory. It helps if it is elegant and parsimonious, though those criteria may not be considered essential. In technology, a solution has to work, of course, but it also has to be efficient, cost-effective, durable, possibly aesthetically pleasing, and so on. There may also be critical considerations relating to social and environmental impact. Technologies are rarely 'good' in an absolute sense. Rather, they are good from some perspectives, less good (or even undesirable) from others. In that case, whose perspective is to count, whose interests are to be served, whose values are to be upheld? One person's acceptable risk or cost is another person's intolerable hazard, social disruption or cultural insensitivity. Technology is inescapably a social activity, determined by the prevailing distribution patterns of wealth and power. The curriculum should acknowledge these realities. The extent to which technology can have social, political, economic and environmental impact well beyond that imagined by scientists and engineers is well illustrated in Nye's (1990) book *Electrifying America*:

> In the United States electrification was not a 'thing' that came from outside society and had an 'impact'; rather, it was an internal development shaped by its social context. Put another way, each technology is an extension of human lives: someone makes it, someone owns it, some oppose it, many use it, and all interpret it. The electric streetcar, for example, provided

> transportation, but there was more to it than that. Street traction companies were led into the related businesses of advertising, real estate speculation, selling surplus electrical energy, running amusement parks, and hauling light freight. Americans used the trolley to transform the urban landscape, making possible an enlarged city, reaching far out into the countryside and integrating smaller hamlets into the urban market. Riding the trolley became a new kind of tourism, and it became a subject of painting and poetry. The popular acceptance of the trolley car also raised political issues. Who should own and control it? Should its workers unionize? Did the streetcar lead to urban concentration or diffusion, and which was desirable? Like every technology, the electric streetcar implied several businesses, opened new social agendas, and raised political questions. It was not a thing in isolation, but an open-ended set of problems and possibilities. (pp. ix-x)

Dealing with complex 'real world' problems requires a significant shift from the traditional approaches of scientific problem solving. Traditional mechanistic thinking, with a simple linear chain of cause and effect ascertained through close experimental control, is no longer appropriate. What is needed is a shift to a more holistic, systems style of thinking able to deal with complex webs of relationships, multiple interdependencies, feedback systems and unpredictability. In Capra's (1982) words,

> 'we are trying to apply the concepts of an outdated world view – the mechanistic world view of Cartesian-Newtonian science – to a reality that can no longer be understood in terms of these concepts. We live today in a globally interconnected world, in which biological, psychological, social, and environmental phenomena are all interdependent. To describe this world appropriately we need an ecological perspective which the Cartesian world view does not offer' (pp. 15–16).

As indicated earlier, the curriculum proposals outlined here are unashamedly intended to produce activists: people who will fight for what is right, good and just; people who will work to re-fashion society along more socially-just lines; people who will work vigorously in the best interests of the biosphere. It is here that the curriculum deviates sharply from STS courses currently in use. The kind of scientific literacy under discussion here is inextricably linked with education for *political literacy* and with the ideology of education as social reconstruction. The kind of social reconstruction I envisage includes the confrontation and elimination of racism, sexism, classism, and other forms of discrimination, scapegoating and injustice; it includes a substantial shift away from unthinking and unlimited consumerism towards a more environmentally sustainable lifestyle that promotes the adoption of appropriate technology. There are two major aspects to this element of the curriculum: *political education* and *values education*. It is to the latter that I now turn my attention.

Changing values and changing lifestyle

Science and technology education has the responsibility of showing students the complex but intimate relationships among the technological products we consume, the processes that produce them, the values that underpin them and the biosphere that sustains us. Failing to do so, on spurious grounds of disciplinary purity or rigour, is simply reinforcing the status quo and contributing to the problems. As Martin Luther King said, in a somewhat different context, 'If you are not part of the solution, you are part of the problem'. In an issues-based curriculum oriented towards sociopolitical action, it is not appropriate to regard environmental problems as matters of careless industrialization and inexpert management of natural

resources. Such an approach ignores the underlying causes of the problems – the values underpinning industrialization and the exploitation of natural resources. It is dangerously misleading because it suggests that science itself can solve the problems by simple technical means. In that sense, the approach depoliticizes the issues, thereby removing them from the 'realm of possibility' within which ordinary people see themselves as capable of intervention. As a consequence, dealing with environmental problems is left to experts and officials, and ordinary citizens are disempowered. Education for sociopolitical action entails recognizing that the environment is not just a 'given', but a social construct. It is a social construct in two senses. First, we act upon and change the natural environment, and so construct and reconstruct it through our social actions. Few parts of the planet are free of mankind's intervention. Continuing rainforest clearance in countries such as Brazil and Indonesia in pursuit of short-term economic gain is the most spectacular example, of course, but even the large 'unspoiled' areas of European countryside show the indelible imprint of previous generations of agricultural workers. Second, we perceive the environment in a way that is dependent on the prevailing sociocultural framework. Our concept of environment itself is a social construct, and so could be different. Indeed, many indigenous peoples do perceive it in significantly different ways (Knudtson & Suzuki, 1992). Joe Cole, a character in Jenny Diski's (1987) novel *Rainforest*, states:

> There is no nature, only Nature – an imaginary state of man's own invention, a realm of concept and language. That is man's place and it is nowhere except inside his head; a mirror image of a distorted fantasy he calls Mankind . . . Nature is a conceit: a man-made garden in which we wander to relax and preen, as we nod to one another in passing, and congratulate ourselves on being us. We created Nature so that we might take pride in how far we have ventured beyond it (pp. 54–55).

Environmental problems are not problems 'out there' in our surroundings, but problems 'in here' (in our heads), in the way we choose to make sense of the world. They are pre-eminently social problems – problems of people, their lifestyles and their relations with the natural world. Indiscriminate clearance of tropical rainforest for non-forest use brings about local problems of erosion, floods and fuel wood shortage, and global problems related to global warming, climate change and loss of biodiversity. While science provides an understanding of the value of the forest, it doesn't contribute much to solving the problems. Solutions will be found, if at all, by dealing with issues relating to poverty (both individual and national), patterns of land ownership, terms of international trade and burgeoning populations. In those countries where birth rates *have* declined, the factors have not been more (scientific) understanding of fertility, but availability of cheap/free contraceptives, less dependence on children as a source of labour and as insurance against old age or accident, decreased child mortality, and greater educational and employment opportunities for women.

By encouraging students to recognize the ways in which the environment is socially constructed, we can challenge the notion that environmental problems are 'natural' and inevitable. If environment is a social construct, environmental problems are social problems, caused by societal practices and structures, and justified by society's current values. It follows that solving environmental problems means addressing and changing the social conditions that give rise to them and the values that sustain them. Science education for sociopolitical action is inescapably an exercise in values clarification and values change. Environmental

problems will not just 'go away', nor will they be solved by a quick 'technical fix' while we blithely maintain our profligate lifestyle. We have to change the way we live; the planet can no longer sustain our present (Western) way of life. Changing our way of life entails changing our values. Acid rain, global climate change, toxic waste, the threat of nuclear holocaust, ozone depletion, loss of biodiversity, increasing deforestation and desertification are all located in our impoverished values. As Ernst Schumacher said in his book *Small is Beautiful*, some thirty years ago, we have to reject our current values of bigger, faster and more powerful, our current preoccupation with higher production and wealth generation, in favour of an orientation towards 'the organic, the gentle, the non-violent, the elegant and beautiful' (Schumacher, 1973, p.29).

A crucial element in this politicized science education is rejection of the notion of *technological determinism* – the idea that the pace and direction of technological change are inevitable and irresistible. We *can* control technology or, rather, we can control the controllers of technology. We can, and should, promote the notion of technological choice, whereby citizens decide for themselves the kind of technology they will and will not use. Addressing alternative values rooted in ecofeminism and/or in the perspectives of indigenous peoples lays the groundwork for a serious consideration of alternative, more environmentally sustainable and appropriate technologies – which Budgett-Meakin (1992) characterizes as technologies which are sensitive to local social, cultural and economic circumstances, capitalize on local skills, ingenuity and materials, make sparing and responsible use of non-renewable resources, and are controlled by the community, thereby resulting in increased self-respect and self-reliance. Adoption of appropriate technology entails rejection of any technology that violates our moral-ethical principles, exploits or disadvantages minority groups, or has adverse environmental impact. The goal is a *humanized* technology: a technology more in harmony with people and with nature, a technology that is energy and materials conserving – that is, based on renewable resources and recycling, and on durability rather than in-built obsolescence and deterioration. Many science curricula promote the view that energy production based on oil or coal consumption, 'hydro' or nuclear power are the only viable alternatives, dismissing the use of wind, solar, tidal and biomass energy production as 'cranky', economically disadvantageous or hopelessly futuristic. Whose interests are being served by failing to make students aware of alternatives and, therefore, likely to demand alternatives? Certainly not those of the wider global community or of the planet as a whole. What is at issue here is not short-term economic gain but long-term environmental health.

It is now a well-worn cliché to say that we live in a global village, and that what we do in our own backyard can impact quite significantly on people living elsewhere in the world. What is also true is that our actions now impact on the lives of future citizens. The ethics of previous generations have dealt almost exclusively with relations among people alive at the same time. In startling contrast, contemporary technology makes an urgent issue of relations with those as yet unborn. In recognizing this new reality we would do well to heed the wisdom of the First Nations people of North America.

> Treat the Earth well. It was not given to you by your parents; it was loaned to you by your children. We do not inherit the Earth from our ancestors, we borrow it from our children.

It is not too much of an exaggeration to say that the degree to which young citizens incorporate sustainable practices in their professional and personal lives will determine the quality of life for future generations. The science curriculum has a crucial role to play in teaching them how to exercise the enormous power of technology responsibly, carefully and compassionately, and in the interests of *all* living creatures. The time is long past when 'alternative technology' can and should be (falsely) equated with the somewhat pejorative term of 'alternative lifestyle'.

The most fundamental element in this values shift is the rejection of *anthropocentrism*, identified by Smolicz and Nunan (1975), some quarter century ago, as one of the ideological pivots ofWestern science and science education. Many scholars have argued that anthropocentric thinking, and the consequent objectification of nature, is the root cause of the global environmental crisis (Corcoran & Sievers, 1994; Russell & Bell, 1996). By objectifying nature, people absolve themselves of any moral responsibility for the care and preservation of the natural environment and justify their continued exploitation of natural resources and other life forms. The pervasiveness of anthropocentrism is evident in our common everyday language: we subdue Mother Nature, conquer virgin territory, rape the countryside, achieve mastery over the elements, manage, exploit and control natural resources. To effect the kind of shift in society that I am advocating, we need to replace this anthropocentrism with a *biocentric* ethic comprising the following elements: all things in the biosphere have intrinsic value and an equal right to exist alongside humans; the natural world is not just a resource for human use; all life forms are inextricably interconnected (Russell, 1997). Adopting such an ethic means having respect for the intrinsic value of all livings things, cultivating a sense of compassion and caring towards both human and non-human species, having a concern for maintaining the existence of biological and cultural diversity, and challenging and rejecting all forms of discrimination. Appreciating interconnectedness means acquiring an understanding of the relationships that exist between all natural and human made systems, recognizing that all human actions have consequences that will affect a complex global system that includes human and non-humans species, having an awareness of and acting on choices to maintain an ecologically sound and humane lifestyle. Laszlo (2001) describes the inculcation of this clutch of values as developing a 'planetary ethic' – an ethic which 'respects the conditions under which all people in the world community can live in dignity and freedom, without destroying each other's chances of livelihood, culture, society and environment' (p.78). Laszlo is at some pains to state that abiding by a planetary ethic does not necessarily entail major sacrifices or self-denying behaviour. Striving for excellence, beauty, personal growth, enjoyment, even comfort and luxury is still possible, provided that we consider the consequences of our actions on the life and activity of others by asking:

- Is the way I live compatible with the rights of others?
- Does it take basic resources from them?
- Does it impact adversely on the environment?

Changing pedagogy

Clearly, values cannot and should not be imposed on students from outside. They must be fostered from within. But how? What changes in pedagogy are necessary to

effect such a radical shift in student values? It is well documented that informal learning experiences can sometimes be more effective than formal schooling in bringing about awareness of issues, attitudinal shifts and willingness to engage in sociopolitical action (Ramey-Gassert & Walberg, 1994; Rennie & McClafferty, 1996; Jeffrey-Clay, 1999; Pedretti, 2002). Informal learning experiences are particularly well positioned to facilitate the affective and social components of learning (Alsop & Watts, 1997; Meredith, Fortner & Mullins, 1997). They can provide the fusion of the cognitive, affective and social that is too often absent in the classroom but is essential to the kind of radical shift in attitudes and values on which sociopolitical action depends. It is also well established that education *in* and *through* the environment can play a substantial role in assisting the re-ordering of values and the development of new ones. Gough (1989), for example, describes how the kind of experiences advocated by the Earth Education movement (van Matre, 1979) can be utilized in re-orienting students' environmental understanding.

Some years ago, Woolnough and Allsop (1985) talked about the importance of students 'getting a feel for phenomena' through hands-on experiences in the laboratory as a prerequisite for conceptual understanding. What I am advocating here is 'getting a feel for the environment' – building a sense of ecological relationships through powerful emotional experiences 'in the field'. The key emphases are: sharpening the senses; building key ecological concepts – not just as analytical abstractions but as tools for *seeing* and *understanding*; providing opportunities for solitude; making learning a joyful and magical experience. We should aim to give all students the opportunity to experience the silence and majesty of the forest, mountains and seashore. By learning to be sensitive to the spirituality of the caves, volcanoes and trees – rather than seeing them merely as products of erosion, the outcome of geothermal activity and resources for making paper or furniture – children can recover what many indigenous peoples around the world have never lost: a sense of unity between humanity and the environment. Literature, art, photographs and movies are both a useful substitute for, and a powerful adjunct to, outdoor experiences; they can play a significant role in shifting students' values. Russell and Hodson (2002) suggest that *whalewatching* and other ecotourist activities can be even more effective in preparing the ground for a shift from anthropocentrism to biocentrism and humane education. As Paul Shepard (1982) says, maturity of thought (*wisdom* rather than mere knowledge) arises from connecting with the Earth in the early years of childhood. Without close contact with the natural environment, he argues, we become *infantile adults*: wanting everything now and new; careless of resources and waste; unable to empathize with 'others'; prone to violence when frustrated; despising age and denying human natural history.

Barriers and resistance

Making the kind of changes to the curriculum advocated in this article will not be easy. Much that I have suggested is likely to be disturbing to science teachers, severely testing both their competence and confidence. Traditionally, science education has dealt with established and secure knowledge, while contested knowledge, multiple solutions, controversy and ethics have been excluded. Accommodating to what some teachers will perceive as loss of teacher control and direction will be difficult. Indeed, to teach this kind of issues-based curriculum

science teachers will need to develop the skills and attitudes more commonly associated with the humanities and language arts.

Of course, not all of the issues to be addressed in such a curriculum will be global or even regional; many of the most compelling issues are local. This requires a much greater degree of curriculum flexibility and local decision making than many educational jurisdictions currently favour. These changes raise concerns about assessment and evaluation. Conventional assessment methods do not cope very well when there is no clearly defined outcome, no certain and unambiguous solution; when the curriculum is extended to include sociopolitical action, evaluation is as much about what the community learns from an activity as what the students learn. Clearly, much work will be needed to develop appropriate assessment and evaluation strategies.

Because this approach diverges so markedly from traditional images of science education, it may be strenuously resisted by universities and by the community of scientists. Parents may see it as a 'soft option' to 'proper' science (i.e., abstract, theoretical science assessed by conventional means). Delamont (1990) cautions that attempts to change the image of science could undermine public confidence in science and so have adverse effects on the funding of research. Change may even be resisted by students. They, too, have expectations of science lessons, and sometimes act to restore the familiar when teachers attempt radical change. The problems for science teachers intent on radical change are neatly summed up by Lakin and Wellington (1991, p.187):

> They don't expect reading and discussion or drama and role play – they do expect Bunsen burners and practical work. They don't want to find out that science is not a set of facts, that theories change, and that science does not have all the answers – they want the security of a collection of truths which are indisputable.

As Jenkins (1992) remarks,

> 'these expectations are not simply an aspect of the hidden curriculum of science . . . They are fostered by the unproblematic presentation of science in the media, burnished by members of the scientific community, and form part of the wider attempt to insulate science from influences that are keen to threaten its 'neutrality' and independence' (p.562).

There may be teachers, educational administrators and members of the wider community who perceive the capacity for effecting social change that is located in a body of students who are critically literate in science and technology, and sufficiently politically literate to ensure that their voices are heard, as a threat rather than a triumph of the science curriculum. The more successful this form of education, the more opposition it may generate.

It is clear that radicalizing science education along these lines is a formidable undertaking. Hence it is unlikely to be achieved by conventional strategies for curriculum reform. A curriculum that aims to achieve a critical scientific and technological literacy must, in my view, be based on a model of curriculum development that seeks to encourage and support teachers in becoming critically literate about their own educational practice. Action research is probably the only coherent and viable way of addressing the issues of curriculum evaluation, curriculum development and professional development/teacher education that are central to the implementation of this radically new form of science education. Action research creates and sustains a supportive, critical environment in which groups of teachers who are familiar with the students, the locality and the school

environment work together on theoretical and practical issues related to the design and implementation of a new science curriculum in a critical and supportive environment. A fundamental principle underpinning this approach is that *all* curriculum knowledge should be regarded as problematic, and open to continuous and rigorous scrutiny, critical appraisal and revision. Because we live in such a rapidly changing world our work as curriculum builders is never finished. Action research also assumes that teachers can acquire the expertise necessary for effective curriculum development by refining and extending the practical professional knowledge they already possess through critical collaborative activity supported by researcher/facilitators. Such was the rationale underlying a series of action research projects aimed at addressing five key aspects of science and technology education in Ontario.

- Introduction of an STSE approach into the primary and secondary curriculum.
- Gender issues
- Presentation of a more authentic view of science through the curriculum
- Multicultural and antiracist science education
- The problems of teaching science in elementary school
- The nature of technology education and its relation to science and environmental education

In each case, groups of teachers (many of whom gained academic credit for their involvement) worked with a researcher/facilitator over two academic terms. Hodson, Bencze, Nyhof-Young, Pedretti and Elshof (2002) describe each project in detail and state what was learned about science and science education, and about action research. The authors formulate some guidelines for action researchers in science education and conclude with a chapter that looks at what else is necessary if we are to bring about significant and radical curriculum change in our school science programmes. Even when teachers and teacher educators embrace the kind of science curriculum I have outlined, there may still be much to do to convince the wider public of its desirability and efficacy. As I have argued elsewhere (Hodson, 1999), legitimating and establishing education for sociopolitical action necessitates extensive community involvement and has much in common with notions of 'participatory research' (Hall & Kassam, 1988) – matters that are well beyond the scope of this article.

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